Single-Top at the Tevatron

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on behalf of the CDF and DØ Collaborations

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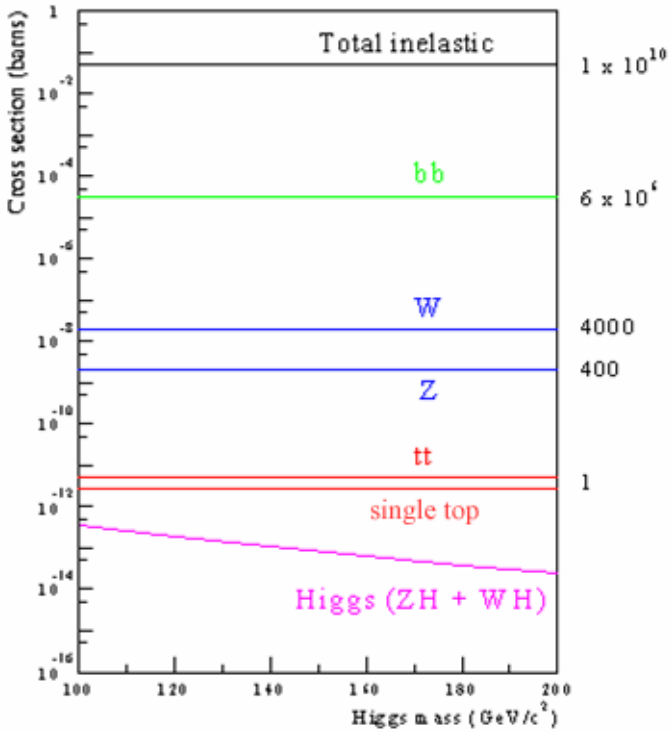
Outline

1. Single-Top Production at the Tevatron
2. Kinematic features
3. DØ Search for Single-Top
4. CDF Search for Single-Top
5. Outlook

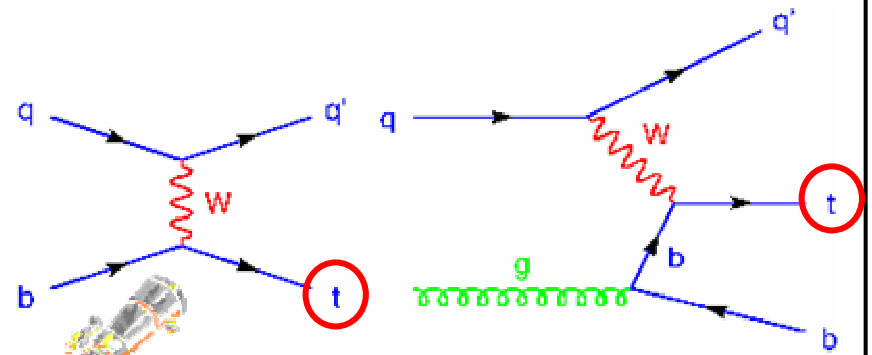


Single-Top Quark Production

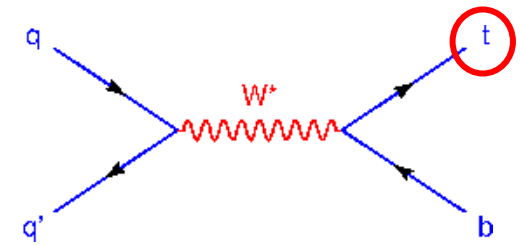
Single-Top Physics:

- Cross-section is about 40% of σ_{tt}
- More difficult to observe due to large backgrounds
- But: $\sigma_{\text{Single-Top}} \sim |V_{tb}|^2$
- Direct access to W-t-b vertex!
- Study top-polarization and test V-A structure of EWK top interaction
- Probe b-quark PDF (t-channel)
- Single top has same final state as Higgs+W (associated) production!
- Test non-SM phenomena:
  - *Heavy W' boson*
  - *Anomalous W-t-b couplings*
  - *FCNC couplings like: $t \to Z/\gamma\, c$*
  - *Special role of top in EWSB ?*
  - *KK excitations*

⇨ High Profile Run II analysis!



t-channel production (Wg fusion)

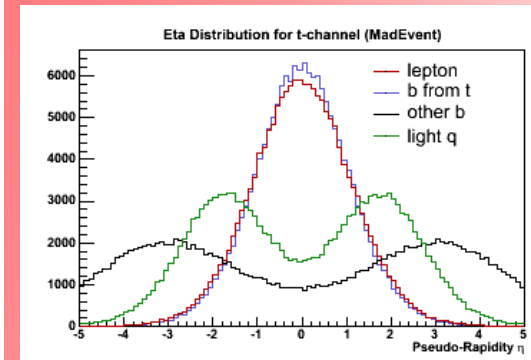


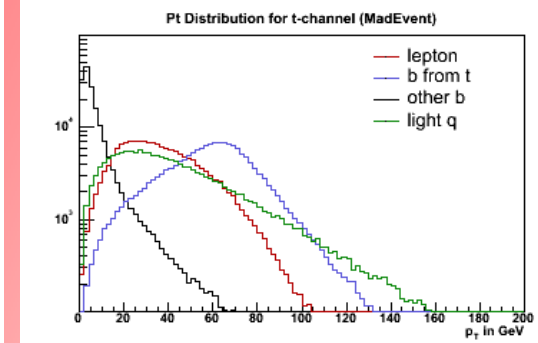
s-channel production (W)*

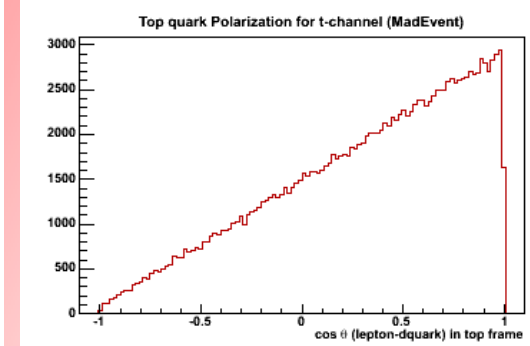
$\sqrt{s}$ =1.96TeV	NLO Cross-sections
t-channel	1.98±0.21 pb
s-channel	0.88±0.07 pb

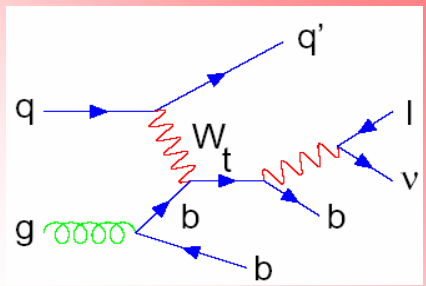
B.W. Harris, E. Laenen, L. Phaf, Z. Sullivan, S.Weinzierl hep-ph/0207055 (2002)

Single-Top Kinematics









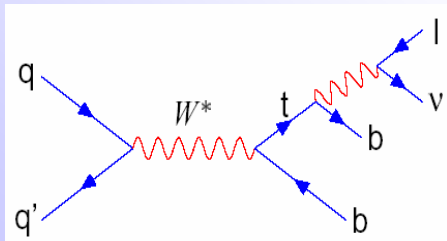
t-channel

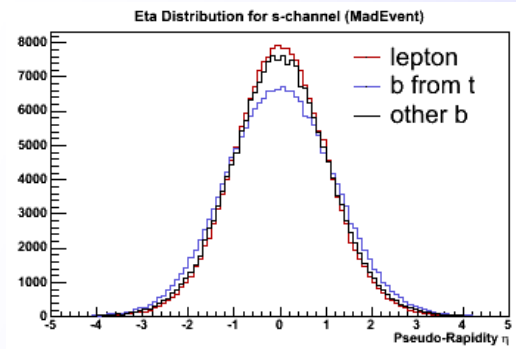
Two orthogonal processes:

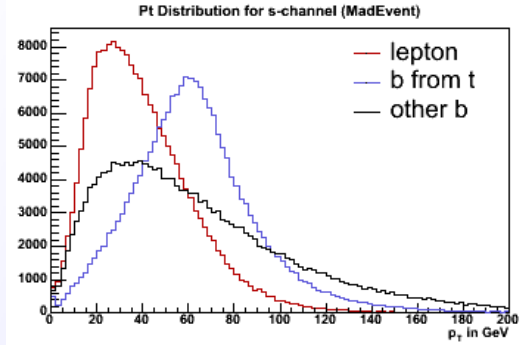
- Both feature **W+2jets**
- At least one b-jet
- Polarization very distinct

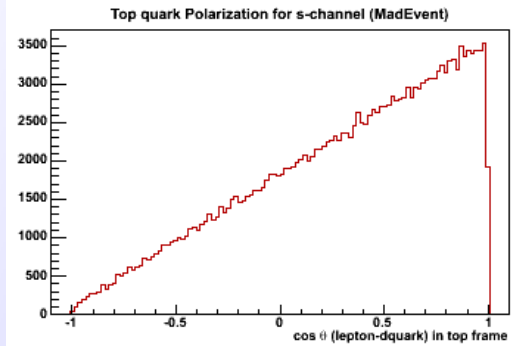
(G. Mahlon, hep-ph/9811219)

s-channel

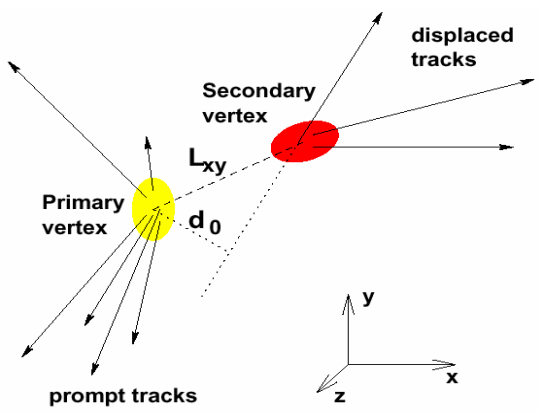


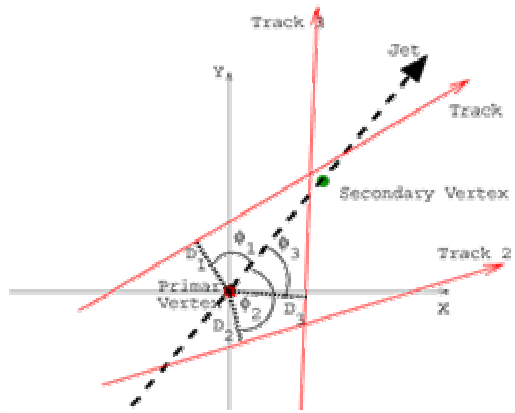


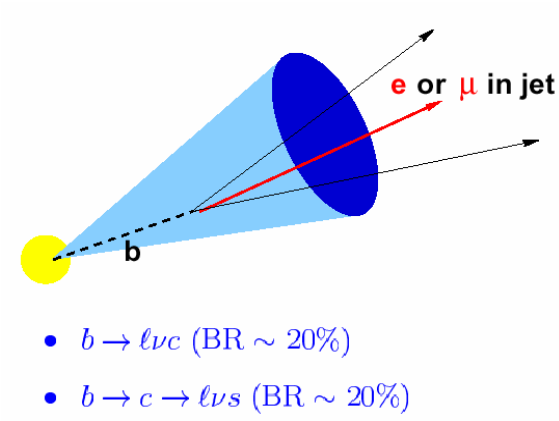




High p_T b-jet tagging







Secondary Vertex Tag

- *Signature of b decay is a displaced secondary vertex*
- *Long lifetime of b hadrons (c_τ ~450 μm)+boost*
- *B hadrons travel L_{xy}~3mm before decay with large charged track multiplicity*

Impact Parameter Tag

- *Probability for an ensemble of tracks (associated with the jet) to originate from the primary vertex*
- *Long lived jets 'peak at 0'*

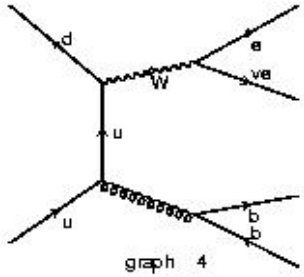
Soft Lepton Tag

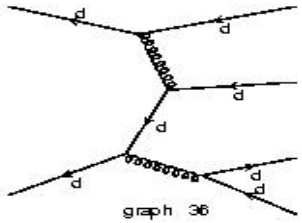
- *Exploits the b quarks semi-leptonic decays*
- *Leptons have a softer p_T spectrum than from W/Z*
- *They are less isolated*

High b-tagging efficiencies are crucial for single-top!

Backgrounds

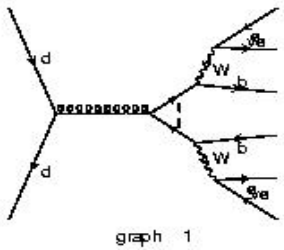
- **W+jets production** (Wjj, Wcc, Wbb, Wc ...)
  - Estimated from data / MC
  - W+HF fractions estimated from MC (Vecbos/Alpgen) normalized to pre-tagged W+jets events in data (CDF)
  - Normalize untagged W+jets sample by probability to tag a jet in the data (DØ)
    - *Probability (TRF) is derived from generic jet sample (assuming same jet flavor composition as W+jets)*

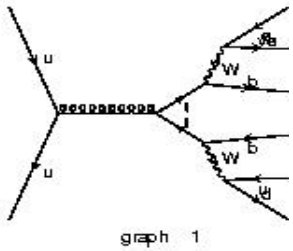




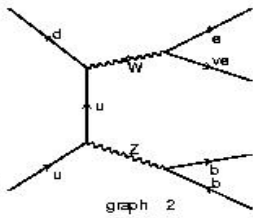
- **Mis-reconstructed multi-jet events (QCD)**
  - Jet mis-identified as lepton
  - Semi-leptonic decay of HF jets
  - Estimated from data

- **Top-pair production**
  - Lepton+jets and di-lepton
  - Estimated from MC





- **Other (WZ, WW, Z ô ττ)**
  - Estimated from MC (CDF) / included in W+jets estimate (DØ)



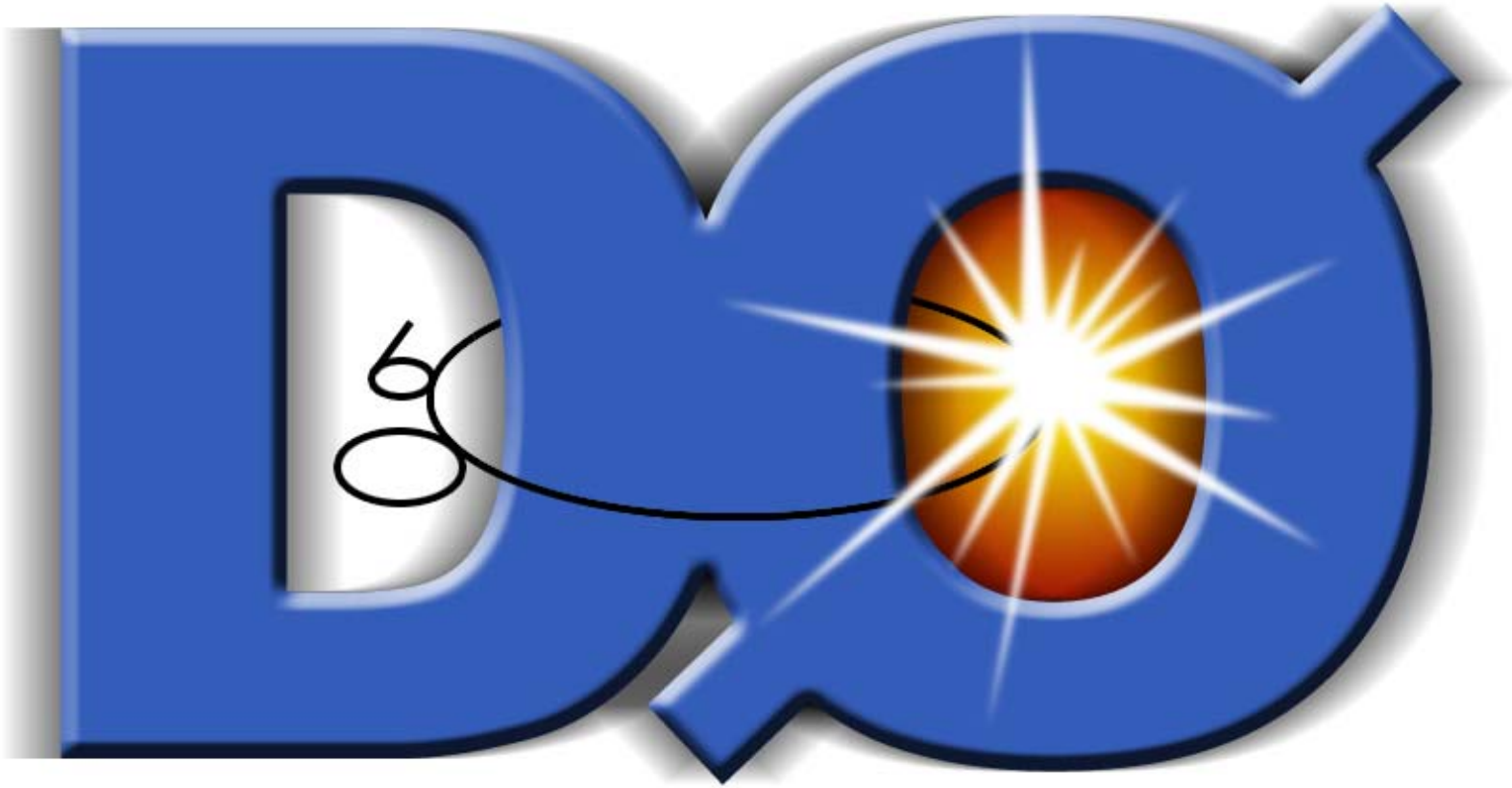
From Run I to Run II

- Tevatron **Run I** results at $\sqrt{s}$ = 1.8 TeV / 107 pb^{-1} data
- Theoretical cross-sections were 30% smaller
  - σ_t = **1.40** pb,
  - σ_s = **0.76** pb
- Both CDF and DØ set upper cross-section limits at 95% C.L.

t-channel:	DØ limit: **22** pb,	CDF limit: **13** pb
s-channel:	DØ limit: **17** pb,	CDF limit: **18** pb
Combined:		CDF limit: **14** pb

- In **Run II** we benefit from:
  - Higher beam energy
  - Higher cross-sections
  - More data – right now CDF/DØ have >250 pb^{-1}
  - Better detector acceptance

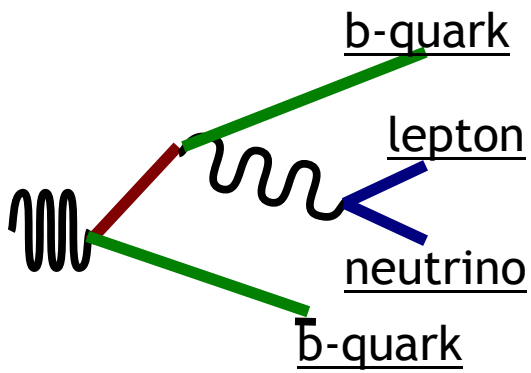
DØ Search for Single Top



Event Selection

Pre-selection:

- **1 lepton** p_T>15 GeV, $|\eta|$<1.1 ($e^{\leq}$) / $|\eta|$<2.0 ($\mu^{\leq}$)
- Missing transverse energy (**MET**) >15 GeV
- **2≤ Njets ≤4**, p_T >15 GeV, $|\eta|$<3.4
- Leading jet: p_T>25 GeV, $|\eta|$<2.5
- **≥1 b-tagged jet**
  - →*secondary vertex (SVT)*
  - →*jet lifetime probability (JLIP) tag*
  - →*soft-μ (SLT) tag*



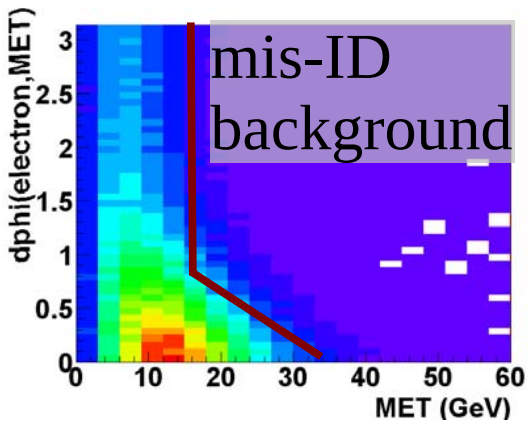
Four orthogonal analysis channels:

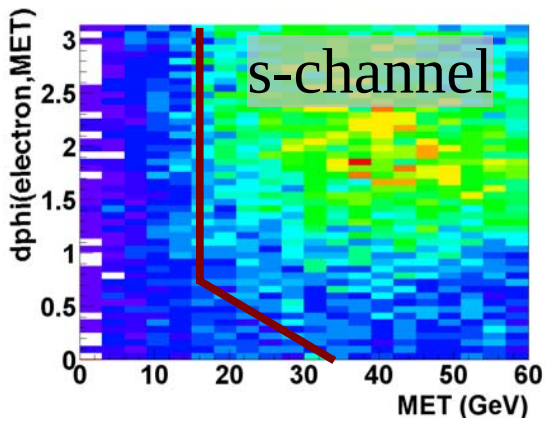
e+jets: SVT,JLIP SLT

μ+jets: SVT SLT

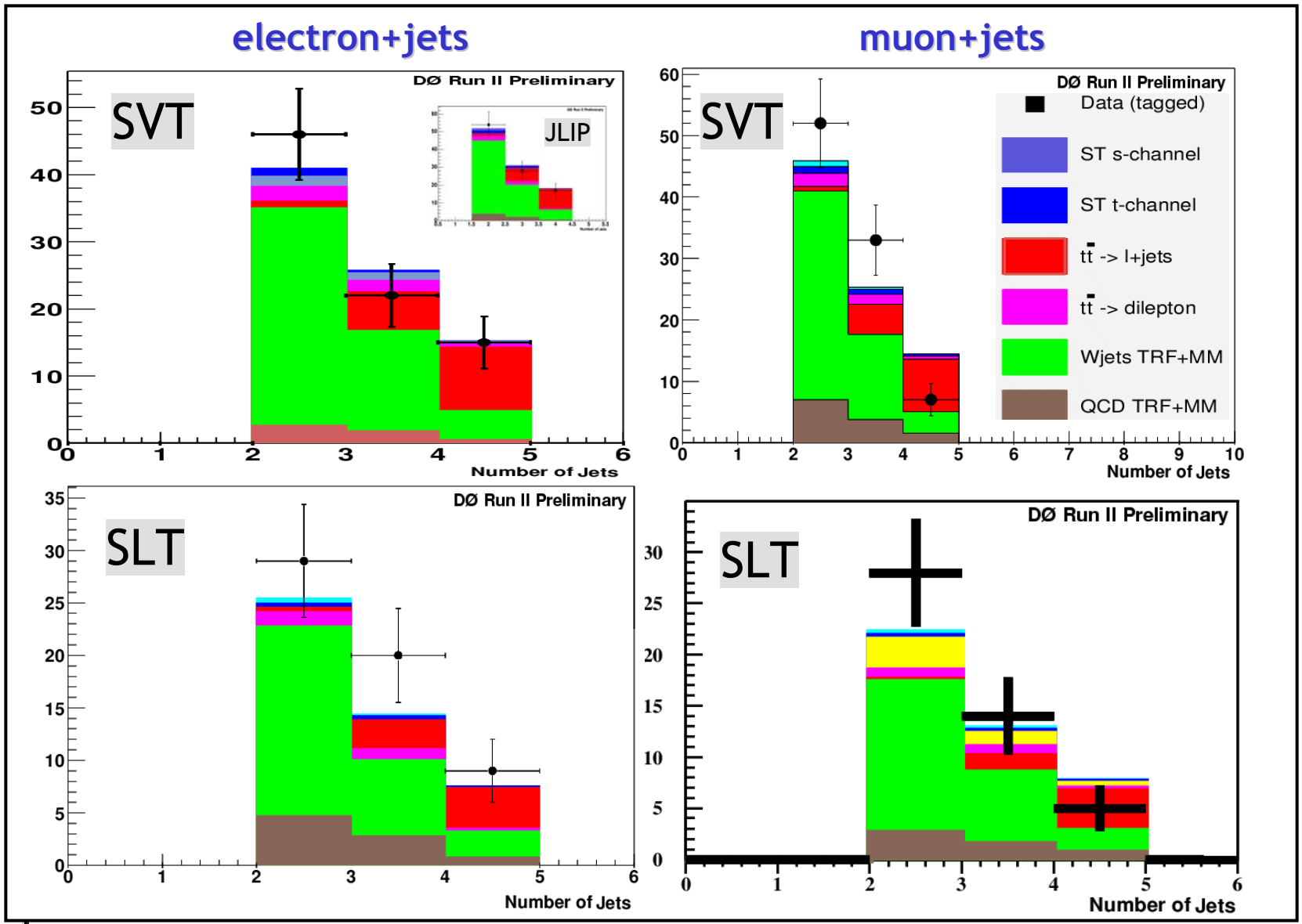
⇒Understand all channels and combine

Triangle cut
Reduces mis-identified lepton background



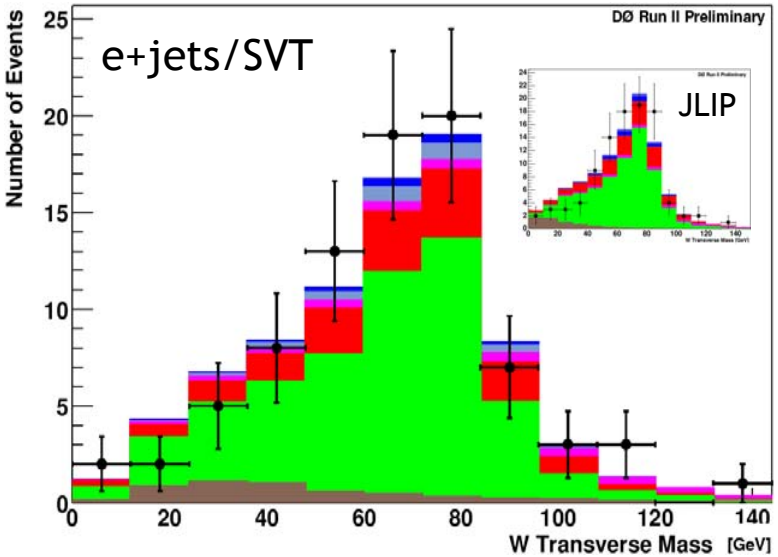


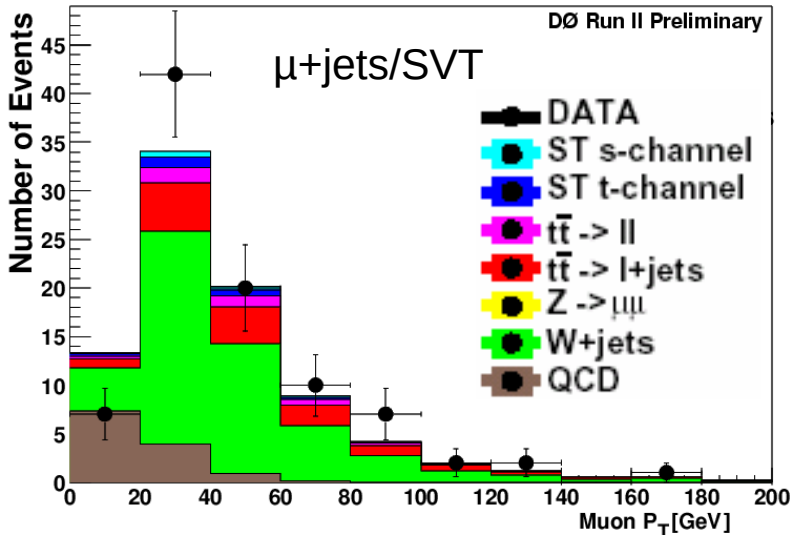
Jet Multiplicity in Lepton+Jets Data

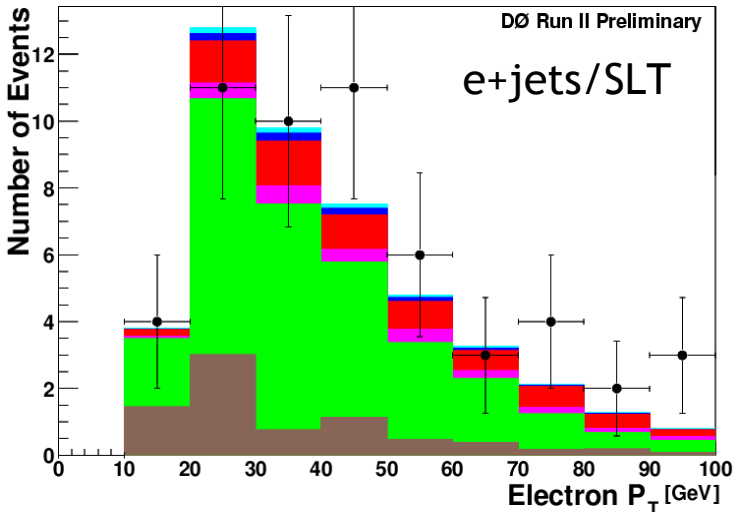


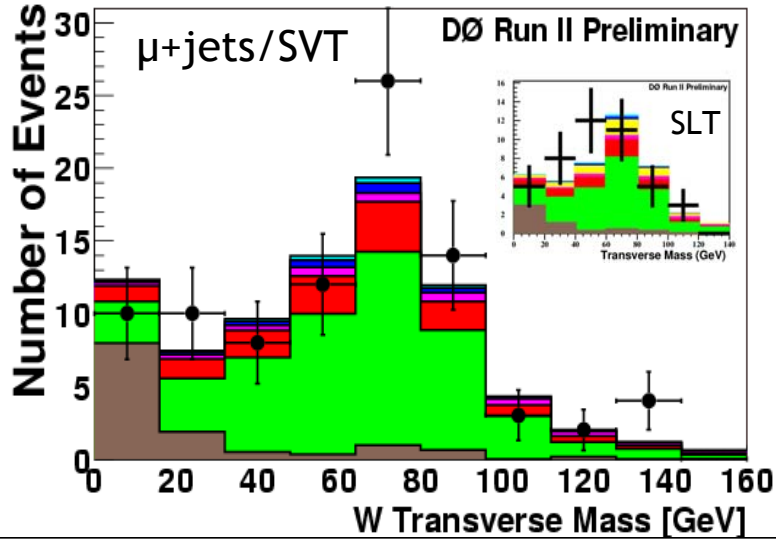
Background Model

- Good agreement between expectation and observation:

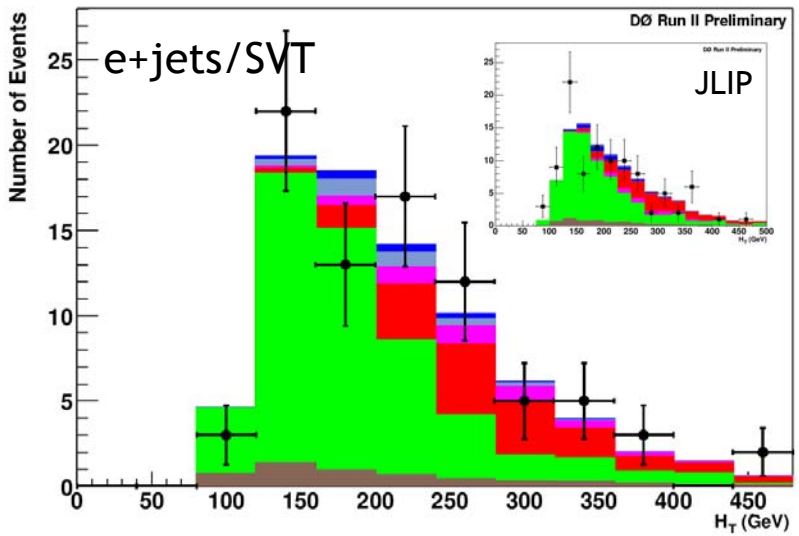








Final Event Selection

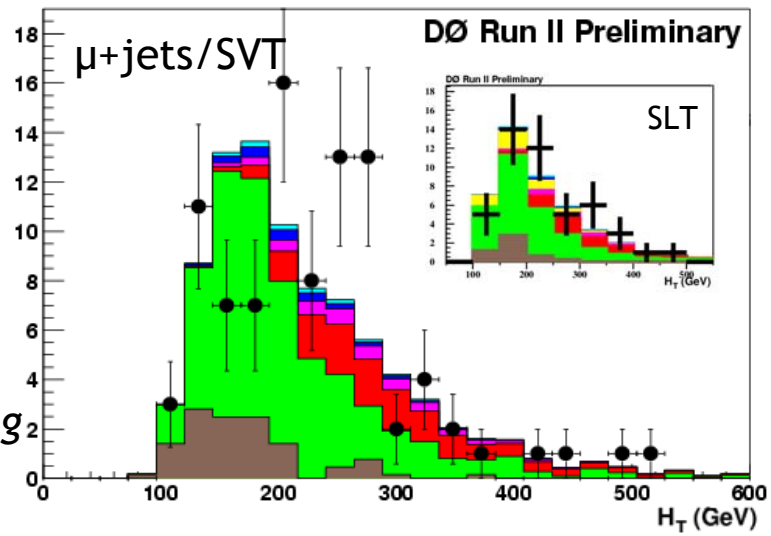


Final Event Selection:

- Dominant background from W+jets
- Cut on **H_T>150GeV**
  - $H_T = E_T(\text{lepton}) + \text{MET} + \sum E_T(\text{jet1,2})$
  - *Reduces W+jets background by ~ 50%*
  - *Reduces Single Top signal by ~ 5%*

Systematic Uncertainties

- Data (dominated by):
  - *tagging-probability: ~20%*
- MC (mainly from):
  - *Jet-Energy-Scale,*
  - *Trigger modelling*
  - *MC flavor-dependent b-tag modelling*
  - *Combined: ~20%*



Results

L~160 pb^{-1}	e+jets			μ+jets	
	SLT	*SVT*	*JLIP*	*SLT*	*SVT*
s-channel	0.6± 0.2	1.8± 0.4	1.8± 0.5	0.6± 0.1	1.3± 0.3
t-channel	0.9± 0.3	2.9± 1.0	3.0± 1.1	0.9± 0.3	2.1± 0.7
tt	9.7± 1.6	23.3± 4.5	24.4± 5.3	6.2± 1.4	18.3± 3.5
non-top	24.7± 4.1	45.8± 8.9	49.7± 9.9	26.9± 4.1	67.0± 11.8
Total background	34± 5	69± 10	74± 12	35± 4	67± 10
Observed	**54**	**63**	**65**	**43**	**76**

- Upper limit on cross-section determined from **Modified Frequentist (CLs) method**

- Combination of e+jets and μ+jets for SVT and SLT analysis channels:

Sensitivity already better than Run I but…**this is just half of the analysis!**

Stay tuned!

DØ Run II preliminary

A priori expected 95% Cross-Section Limit

s-channel: <**14**pb · t-channel: <**18** pb · Combined:<**16** pb

DØ Outlook

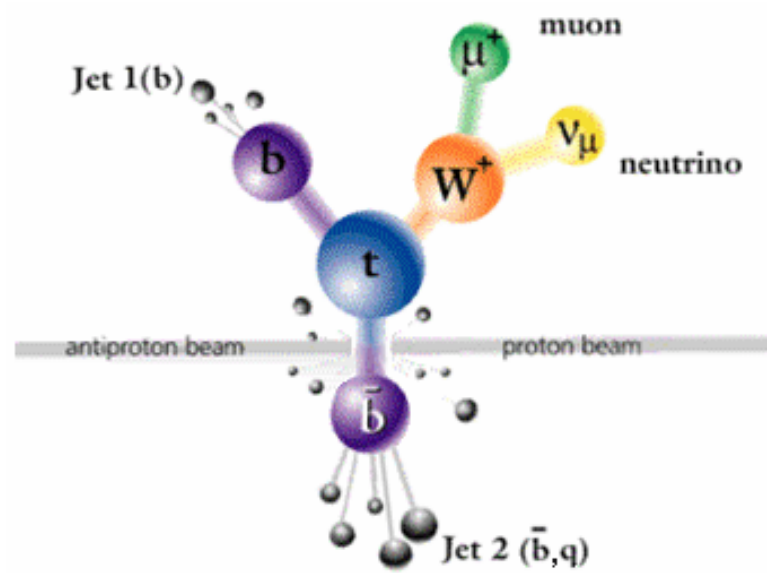
- DØ Run II single top search program is on its way
- Sensitivity from Run I already exceeded
- Preliminary result expected by end of this summer
- DØ is working towards observation of single top production
  - *Collecting more data (increase statistics)*
  - *Improve detector understanding (reduce systematics)*
  - *Keep acceptance high*
  - *Improve analysis*

CDF Search for Single Top

Event Selection

Event Selection:

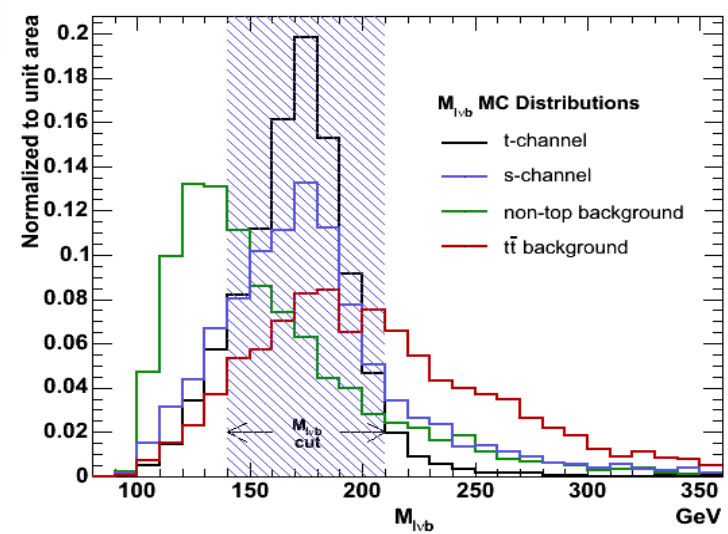
- **1 Lepton,** E_T >15 GeV, $|\eta|$<1.0
- **Missing E_T** (MET) >20 GeV
- **2 Jets,** E_T >15 GeV, $|\eta|$<2.8
- **≥1 tagged b-jet**, (SecVtx)



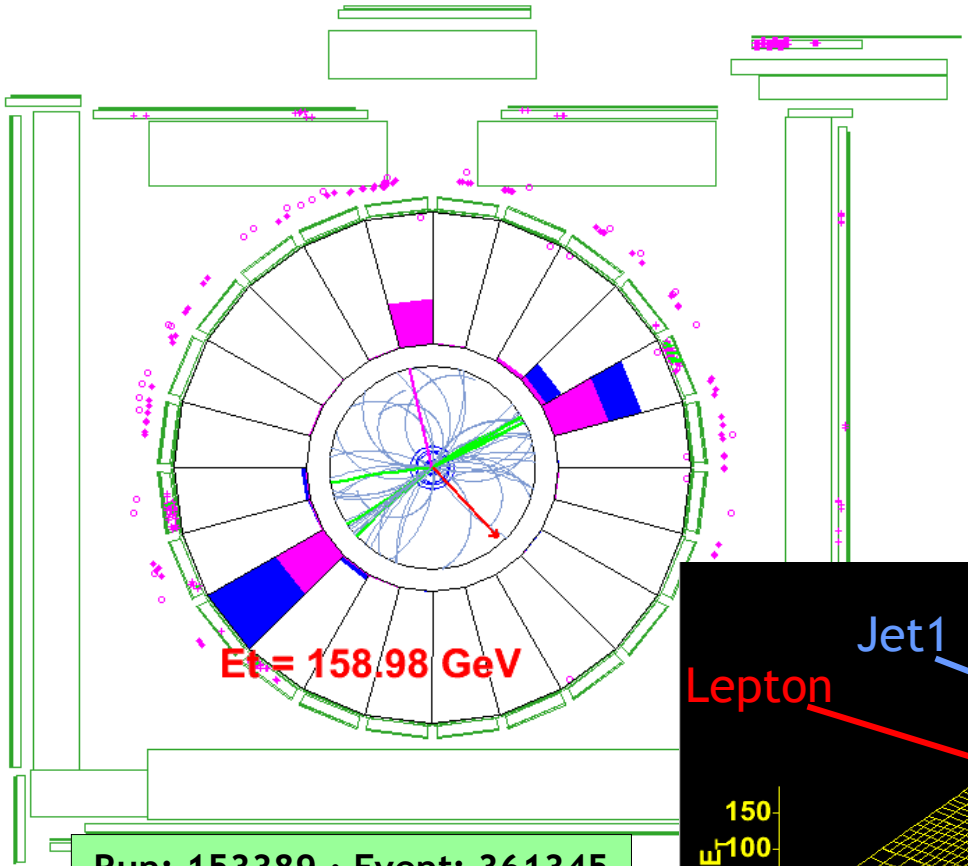
Topological Selection:

- **140 GeV < $M_{l\nu b}$< 210 GeV**
- **Leading Jet E_T>30 GeV** (t-channel only)

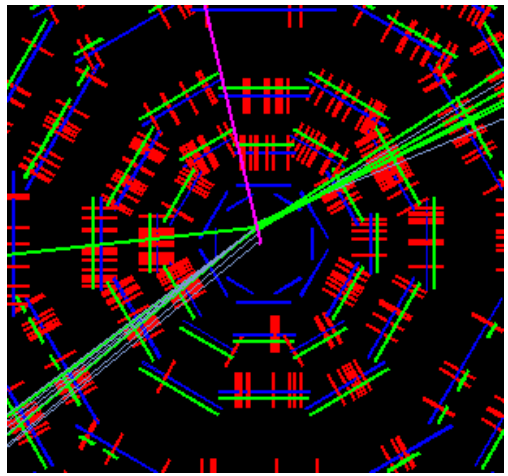
	Combined search	*t-channel search*
s-channel	1.19± 0.25	1.16± 0.24
t-channel	2.39± 0.56	2.34± 0.54
tt pairs	3.47± 1.04	3.39± 1.02
non-top	20.7± 4.1	17.4± 3.3
Total Predicted	27.8± 4.3	24.3± 3.5
Observed	**28**	**25**

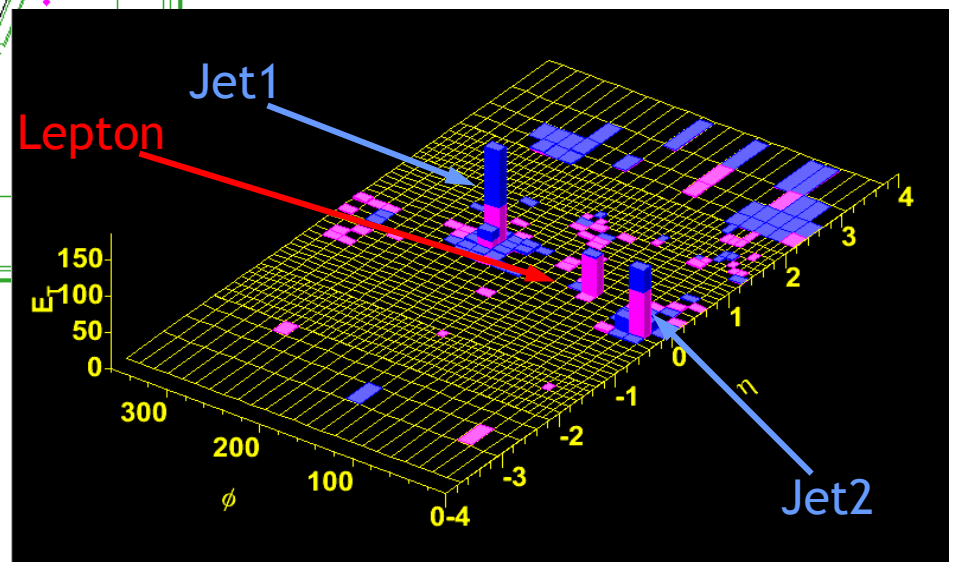


Event Display



SVX L1/2/3 and L00





Run: 153389 · Event: 361345

- CEM Electron E_T=50.9 GeV
- MET=27.4 GeV
- Jet1 E_T=175.2 GeV, η=0.45
- Jet2 E_T=147.2 GeV, η=-0.13

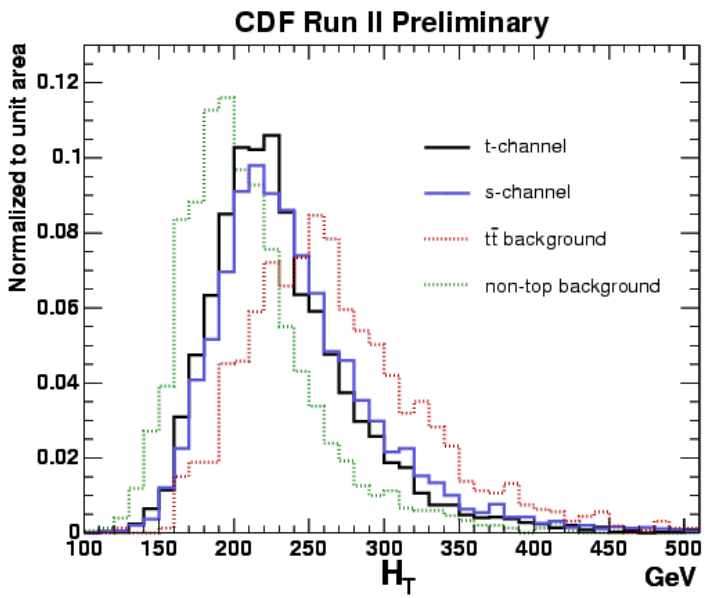
Search Strategy

- *Employ discriminant variables to perform single-top search*
- **Combining channels: → Aim for evidence of single-top**
- **Separating channels: → Essential for Physics measurements**

Combined Search:

$H_T = E_T(\text{lepton}) + \text{MET} + \sum E_T(\text{jets})$

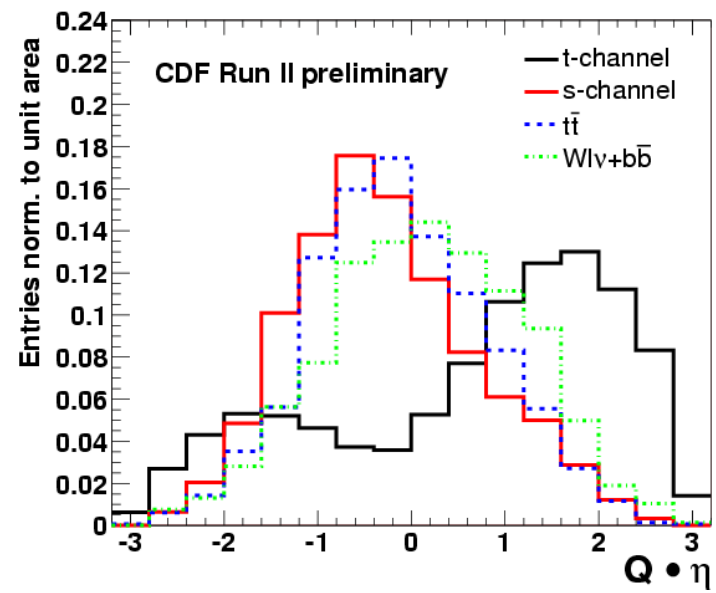
- s/t-channel shapes very similar



t-channel search:

$Q(\text{lepton}) \bullet \eta\ (\text{forward jet})$

- Very distinct shape for t-channel

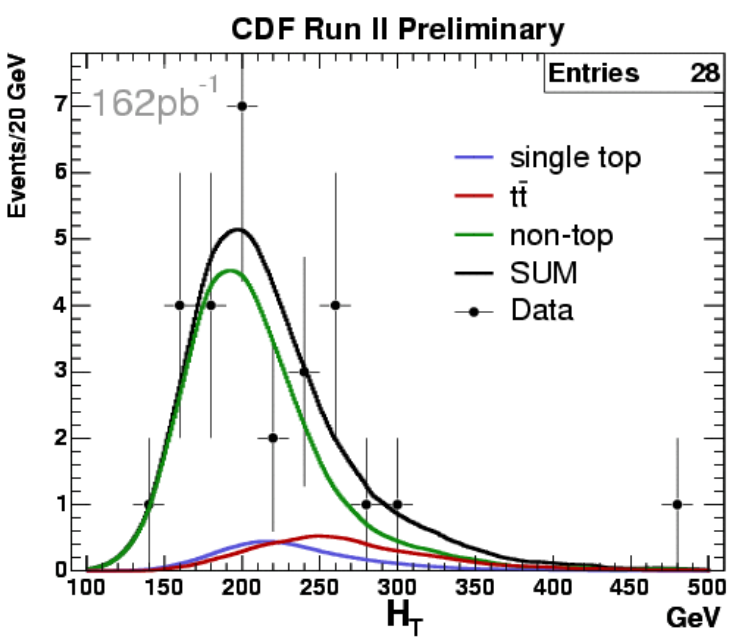


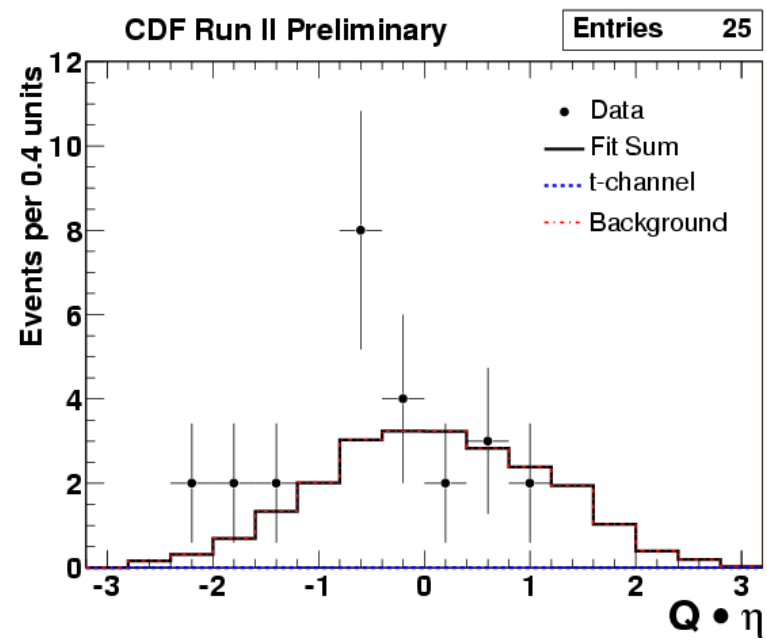
Likelihood Fit to Data

- **Maximum likelihood fit to data H_T or $Q \bullet \eta$ distributions** using templates determined from MC: *single-top (PYTHIA), tt (Pythia), non-top: Wbb (ALPGEN)*
- **Background** allowed to float but (Gaussian) **constrained** to expectation.
- Fit parameters: $\beta_i = \frac{\mu_i}{\mu_i^{SM}} = \frac{\sigma_i}{\sigma_i^{SM}}$;

Process	β_{fit}	Poisson μ
Single Top	0.64 ± 1.55	2.30 ± 5.55
$t\bar{t}$	0.98 ± 0.30	3.40 ± 1.03
Non-top	1.04 ± 0.19	21.46 ± 3.81
$\Sigma\,\mu$	–	27.16

Process	β_{fit}	Poisson μ
t-channel	0.0 ± 1.39	0.0 ± 3.3
s-channel	1.01 ± 0.21	1.2 ± 0.24
$t\bar{t}$	1.06 ± 0.29	3.6 ± 1.0
non-top	1.04 ± 0.16	18.1 ± 2.7
$\Sigma\,\mu$	–	22.8





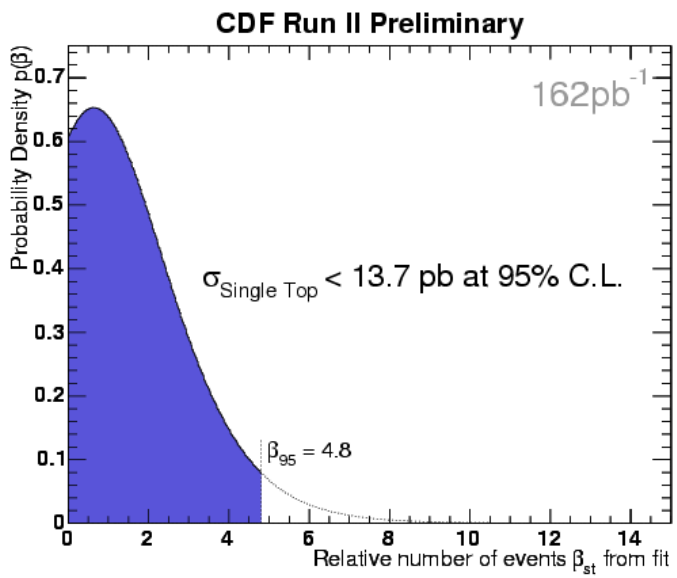
Cross-Section Limits

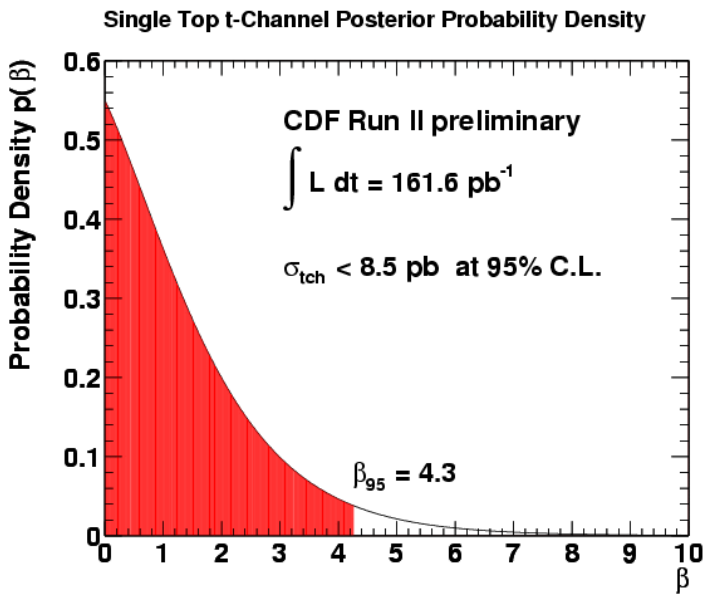
- Upper limit on cross-section determined from a **Bayesian approach**.
- Systematic uncertainties included by convolution procedure:

$$L_{sm}(\beta) = \int_{-\infty}^{+\infty} L(\beta') \cdot \frac{1}{\sigma(\beta)\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{\beta-\beta'}{\sigma(\beta)}\right)^2\right) d\beta'$$

$\sigma^2(\beta)=\Delta^2_{Norm}+\Delta^2_{Shape}$

- *Normalization*: Δ_{Norm}~20%
- *Shape*: Δ_{Shape} ~22% (combined)
  ~54% (t-channel)





$\sigma_{Single\ Top}$ < 13.7 pb at 95% CL

σ_t < 8.5 pb at 95% CL

$\sigma_{Single\ Top}$ < 14.1 pb at 95% CL ô *a priori* ö σ_t < 11.3 pb at 95% CL

CDF Outlook

- First pass of search for single-top in Run II completed
- Currently updating analysis with improved SecVtx b-tagger and new MadEvent single-top Monte Carlo
- Second pass will employ improved detector acceptance
  - *Lepton ID in forward region (CDF Plug already used by EWK/Top analyses)*
  - *Complementary b-tagger (SLT/JPB)*
  - *b-tagging in forward region (silicon stand-alone tracks)*
- Four advanced analysis techniques in preparation:
  - *Likelihood ratio technique*
  - *Multivariate analysis (AIDA)*
  - *Neural-network analysis*
  - *Search using full event-probability information*

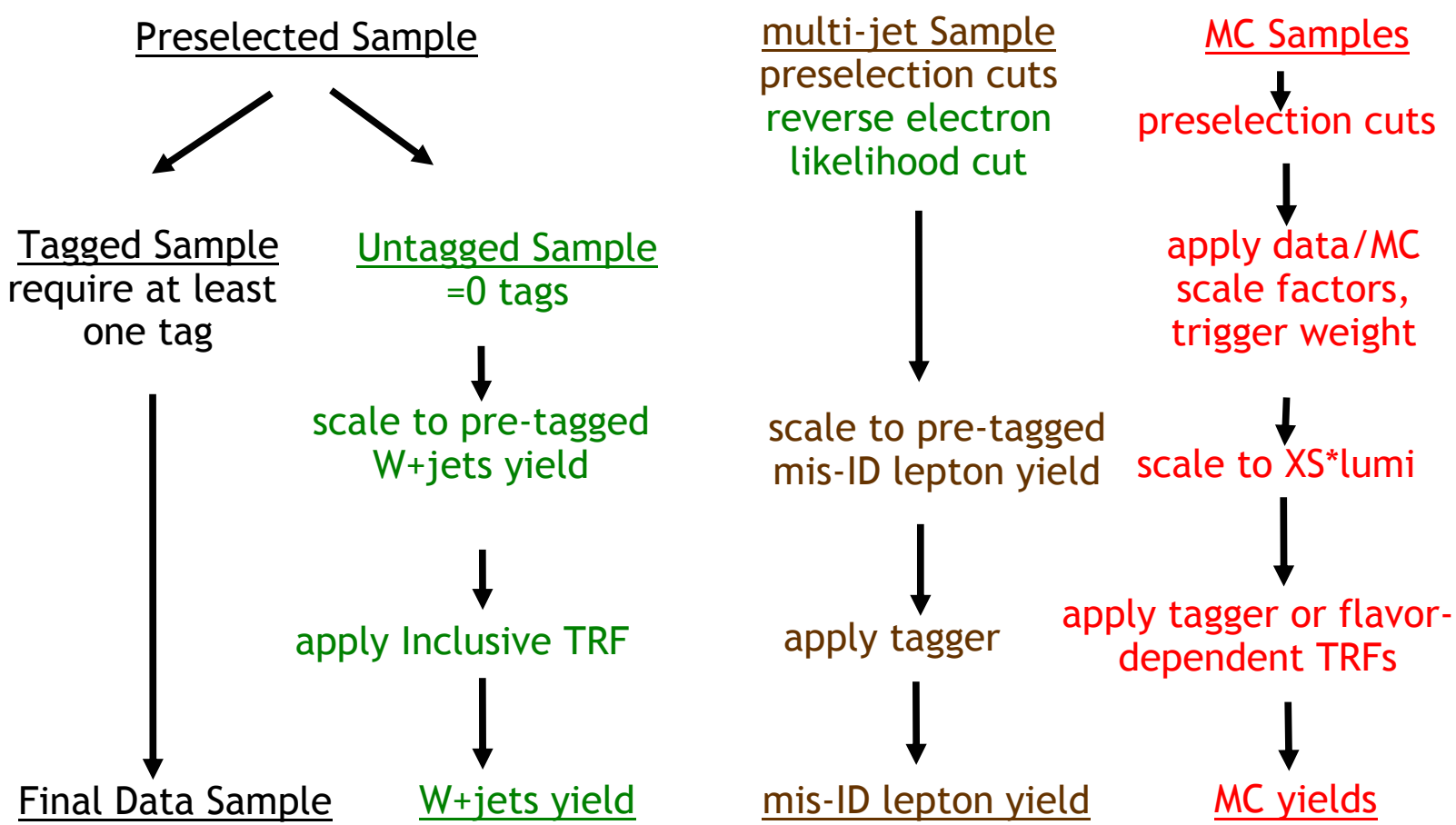
Stay tuned!

Summary

- CDF and DØ accumulated more data than in entire Run I (more than factor of 2).
- Preliminary results with ~160 pb^{-1} set promising single-top limits
- Many improvements are needed to observe single-top in the next 1-2 years
- But, **observation of single-top is feasible in Run II!**

Backup Slides

Background Estimate

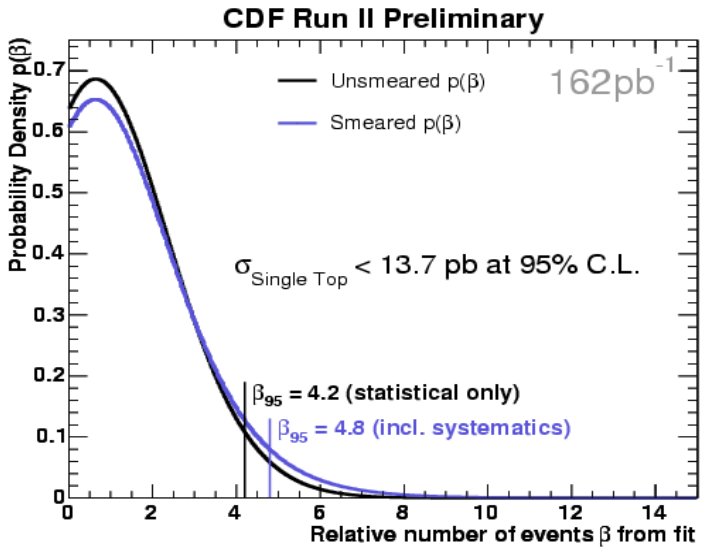


Backup Slides (CDF)

Incorporating Systematic Uncertainties:

$$\mathbf{L_{sm}}(\beta) = \int_{-\infty}^{+\infty} \mathbf{L}(\beta') \cdot \frac{\mathbf{1}}{\sigma(\beta)\sqrt{\mathbf{2}\pi}} \exp\left(-\frac{\mathbf{1}}{\mathbf{2}}\left(\frac{\beta-\beta'}{\sigma(\beta)}\right)^{\mathbf{2}}\right) \mathbf{d}\beta'$$

$$\sigma^2(\beta)=\Delta^2_{\text{Norm}}+\Delta^2_{\text{Shape}}$$



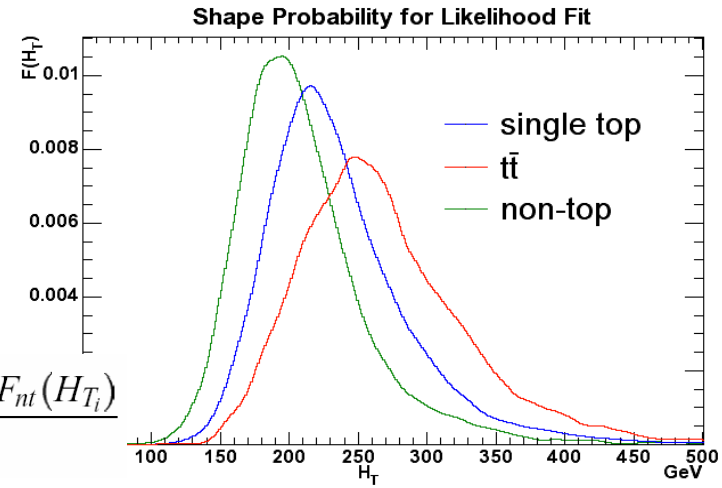
	Relative Uncertainty		
Source	t-channel	s-channel	combined
Jet energy scale	6.7%	7.2%	6.9%
ISR	6.5%	8.7%	7.2%
FSR	2.6%	2.9%	2.7%
PDF	8.9%	1.0%	6.3%
Generator	5.8%	1.4%	4.4%
Top quark mass	5.3%	1.0%	4.0%
ϵ_{evt}	11.2%	11.2%	11.2%
luminosity	6%	6%	6%
Quadratic Sum	19.9%	17.4%	18.5%

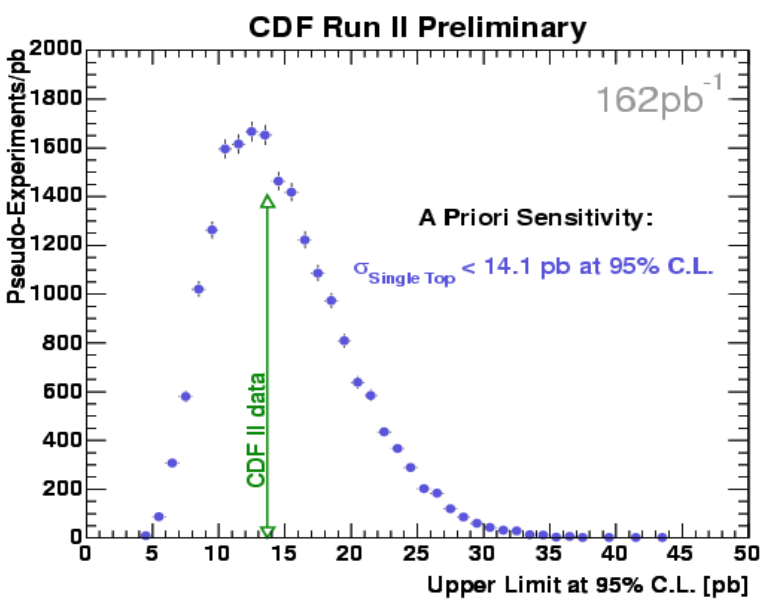
Effect	Δ_{SHAPE}	
	Combined	t-channel
Jet E_T scale	20.9 %	21.5%
ISR	3.2 %	6.8%
FSR	2.4 %	1.0%
Signal generator	1.2 %	21.1%
Top mass	6.2 %	6.7%
PDF	1.1 %	4.3%
Background Model	1.2 %	43%
TOTAL	22.3 %	53.5%

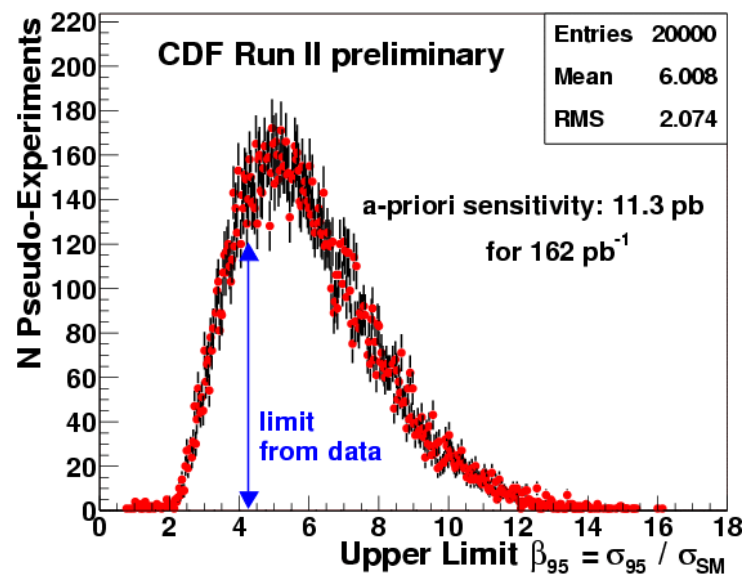
A Priori Sensitivity:

- 20 000 pseudo-experiments
- Extract 95% C.L. for each experiment
- Take **median** of distribution as the *a priori* sensitivity to real data

$$\mathcal{L}_{Poisson/Shape} = \frac{e^{-n} n^N}{N!} \prod_{i=1}^{N} \frac{N_{st} F_{st}(H_{T_i}) + N_{t\bar{t}} F_{t\bar{t}}(H_{T_i}) + N_{nt} F_{nt}(H_{T_i})}{n}$$



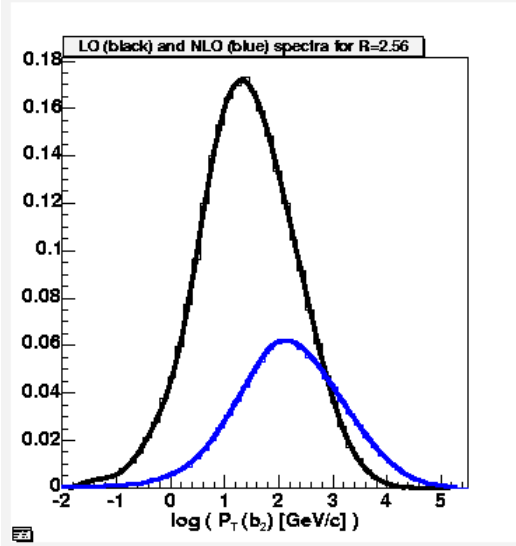


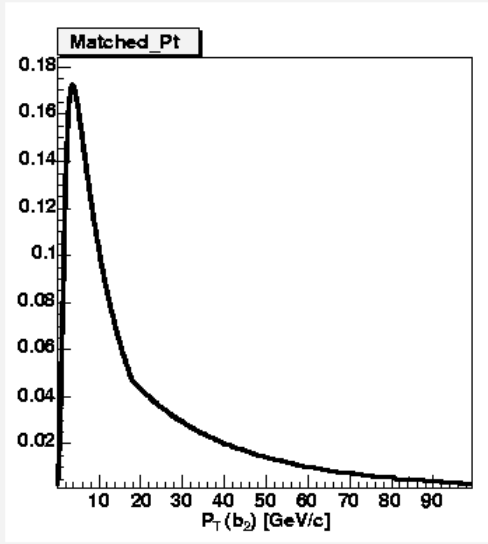


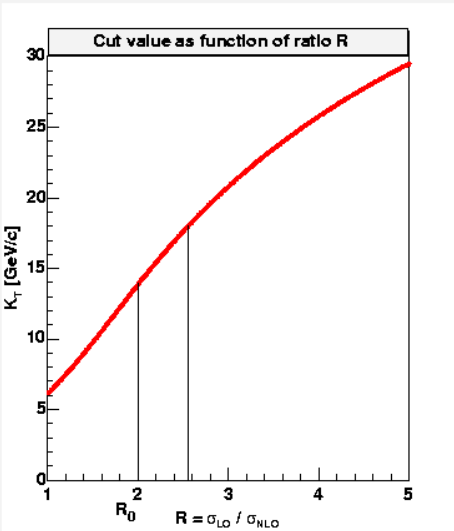
Backup Slides (CDF)

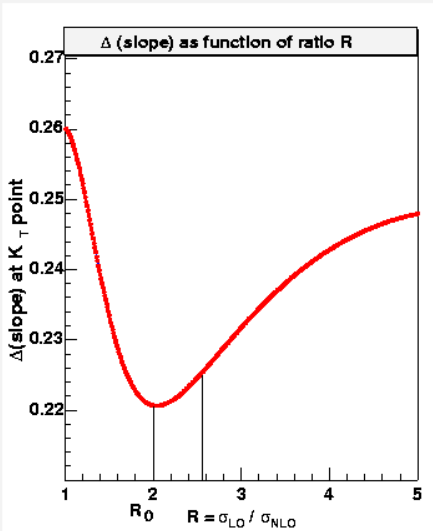
Matching of t-channel:

- Combining LO/NLO contribution by **matching the p_T spectrum of 2nd b**
- Method described in CMS note 2000/065
- Ratio $R=\sigma_{LO}/\sigma_{NLO}$









- R=2.56 (MadEvent)
- Merge point found to be **K_T=18.0 GeV/c**
- Plot shows dependence of K_T on R (and matching slope)

Backup Slides (CDF)

Non-top background estimate:

- From CDF Lepton+Jets 'Method2 background calculation' + analysis dependend scale-factors

Process	Combined Search	t-channel Search
Wbb	5.2 ± 2.2	4.5 ± 1.9
Wcc	2.1 ± 1.1	1.8 ± 0.9
Wc	4.6 ± 1.3	4.0 ± 1.1
Mistags	4.3 ± 1.2	3.1 ± 0.9
Non-W	3.3 ± 0.9	2.9 ± 0.8
DiBoson	1.1 ± 0.3	1.0 ± 0.3
Sum	20.7 ± 4.1	17.4 ± 3.3